

LARGE WIND ENERGY CONVERTER - GROWIAN 3 MW

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INTRODUCTION

The large wind energy converter GROWIAN has the function of producing electrical energy from the natural movements of the wind. A two-blade rotor mounted on the tower is rotated by the action of wind and transfers its power via a gearbox to a generator. The electrical energy thus obtained is then fed directly into the existing supply network.

The plant was designed with reference to a plant site in the North German coastal area. The design of the plant permits a long-term optimal exploitation of wind energy through the use of advanced, proven engineering techniques.

MAIN FEATURES OF THE GROWIAN

The main features of the plant, as shown in figure 1, are:

- Two-blade rotor with pendulum hub
- Leeward mounting of the rotor
- Blade construction: steel-spar design with glassfiber airfoil
- Single stayed tower
- Controlled orientation of the nacelle and rotor into the wind

SYSTEM DATA

Rated capacity	3 MW
Mean annual energy output	12 GWh
Power-to-area ratio	380 W/m ²
Rated wind speed	11.8 m/s
Cut-in speed	6.3 m/s
Cut-out speed	24 m/s
Rotor diameter	100.4 m
Rotor speed	18.5 rpm \pm 15%
Hub height above ground	100 m
Mass of tower head with rotor	240 t

ENERGY YIELD

Calculations were based on an annual mean wind velocity of 6 m/s measured 10 m above ground. This average corresponds to the prevailing wind speed at a coastal site in the North German Plain. The installed capacity of 3 MW yields an annual energy output of 12 GWh. Figure 2 plots the power and the power duration curve. It can be seen that no power is produced 23% of the operating time owing to insufficient wind speeds. Forty-eight percent of the time the output falls below the rated capacity, while the plant operates at rated capacity 27% of the time. The plant is shut down 2% of the time as a result of excessive wind speeds.

The performance characteristics of the plant are shown in figure 3. The plant normally operates in the static control range. The extended limits of the dynamic control range are used for controlling brief fluctuations in the rotor speed. The rated capacity at nominal rotor speed is attained at a wind speed of 11.8 m/s. At higher wind speeds the surplus wind energy must be eliminated. To achieve this, the blade pitch is adjusted so that even at high wind speeds no more than the rated capacity is produced (fig. 4). The power output up to the cut-out point therefore corresponds to the output at the rated wind speed.

The efficiency of the aerodynamic conversion of a wind generator is characterized by the power coefficient ($c_p - \lambda$) chart as given for the GROWIAN in figure 5.

ENVIRONMENTAL IMPACT

The GROWIAN has no detrimental effects on the environment as it produces no noxious substances. The need for a pleasing appearance has always received special attention.

CONSTRUCTION OF THE GROWIAN

As shown in figure 1, the wind converter comprises the main components of tower, nacelle, rotor, and their mechanical and electrical equipment.

Tower and Nacelle

The tower is a slender cylindrical shaft of reinforced-concrete or alternatively of steel (fig. 6). It has an outside diameter of 3.5 m and a height of 96.6 m. The tower contains a spiral staircase, a lift, cable shafts, and the lifting cables for the tower head. Three pairs of cables are attached to the stay ring in the upper third portion of the tower and are strung to foundations in the ground.

The cylindrical nacelle is mounted atop the tower in such a way that it can be adjusted in yaw with reference to the wind. It accommodates the rotor, the gearbox, the generator, and various other units.

The shell-type welded housing has a diameter of 6 m and a total length of 22 m including the rotor mounted on the lee side. On the windward side a spar approximately 20 m long extends outwards, the tip of which contains the wind measuring instruments. Figure 7 shows a cross-sectional view of the nacelle. The collar extending downward houses the block and tackle system for raising the tower head, which is completely assembled on the ground. When raising the tower head, the tower shaft passes through the nacelle. The junction to the rotor is formed by the rotor bearing which is built into the hub support tube.

Rotor

The GROWIAN employs a two-blade rotor 100.4 m in diameter. It is based on the principle of converting energy by utilizing aerodynamic lift. The requirements of strength and stiffness within practicable dimensions have been met for the first version by a steel-spar rotor blade 46 m in length which is assembled in three segments (fig. 8). The steel spar extends from the blade root to the blade tip and is given its airfoil form by mounted glass-fiber molded segments (fig. 9). The spar and skin of the blade were selected for their ability to withstand loads. The airfoil section was specially designed as a laminar airfoil. A rotor blade with a 35 m composite segment is presently being developed.

The blades are mounted on the pendulum hub and can rotate about their vertical axes on antifriction bearings so that their angle of attack can be adjusted by means of a motor-driven linkage in order to control the power output of the rotor. The pendulum hub protects components subjected to high loads such as the rotor blades, the tower, the tower bearing, and the nacelle from moments resulting from differential wind loads on the two blades. Excessive rotor speeds are precluded without resort to any extraneous power supply by means of a device actuated by centrifugal force which allows the rotor blades to turn to their feathered position.

Mechanical Equipment

A planetary gear system with a ratio of 1:81 is used for stepping up the rotor speed of 18.5 rpm to the generator speed of 1500 rpm. The drive of the planetary gear is bolted to the rotor shaft. This system consists of two planetary stages and one spur gear stage and is bolted to the nacelle with a flange. A disk brake located at the high-speed output end of the gearbox is able to arrest the rotor revolving at low speeds or at full speed in an emergency, but only at the cost of its wearing parts. A universal shaft connects the gearbox output to the generator.

The tower head is turned into the wind by geared motors whose pinions engage in a gear ring integral with the tower.

Electrical Equipment

The energy obtained from the wind converter is fed into the local supply network with due regard to economic considerations. Owing to the large fluctuations in the wind energy available, the most suitable generator is one which is not restricted to a set speed of rotation.

An asynchronous generator (3 MW), whose rotor is energized with alternating current by means of slip rings, lends itself well to this purpose, the frequency of the supply current corresponding to the difference to the synchronous frequency. This unit in the supply network behaves like a synchronous generator. By controlling the electric loading in the rotor circuit, any desired reactive and active current in the given range can be obtained.

A slipring system is provided for transferring the generated current as well as the monitoring and control signals from the rotating tower head to the electric cables in the tower. This system is located at the top of the tower concentric about the tower longitudinal axis.

Servo Control

In order to make operation on a supply network possible, the fluctuations in the speed of rotation resulting from changing wind velocity must be reduced enough to allow the electric generator to process them. The control system has the function of starting the plant in compliance with a prescribed set of data, to keep it within the operating range, and to continue operation or shut the plant down, depending on the momentary wind flow and energy requirements. Furthermore, if the plant is operating in conjunction with the supply network, the frequency and the stator voltage must be held constant.

Power output and speed of rotation are regulated by controlling the blade pitch and the generator moment. The generator deviates elastically in the subsynchronous or hypersynchronous modes of operation whenever fluctuations in the rotor speed occur until the overriding speed regulator has reestablished synchronous operation. A schematic of the operating principles of the control system for power output and speed is shown in figure 10.

Operational Control and Monitoring System

A programmable computer is provided for the operational control and monitoring of the converter. In addition to continuously checking the data, it is also responsible for registering and analyzing the operating condition of the plant and for detecting and signaling any malfunction.

ASSEMBLY AND ERECTION

The steel tower as well as the reinforced-concrete tower are erected on a concrete foundation, which is laid at the site. The 9 m sections of the steel tower are set on top of one another with a crane, are bolted together, and then welded (fig. 11). The concrete of the reinforced-steel-concrete tower is formed with the aid of sliding molds. At the same time the plant building is erected.

When the tower has reached a height of 10 to 15 m, the shell components of the nacelle are placed over the tower shaft and are welded in place. The rotor shaft and the pendulum frame are positioned in their bearings with the aid of suitable lifting gear. The rotor is assembled in a horizontal position. The three blade segments are bolted and welded together in the steel sector. After the tower and the nacelle with rotor have been completed, the tower head is raised with the aid of the built-in hoist. The tower shaft passes through the nacelle.

PLANT RELIABILITY

Special emphasis was placed on operational reliability in both the designing of the plant and the dimensioning of its components. The measures taken ensure that the CROWIAN is not endangered in its operation and does not constitute an environmental hazard even under the most inclement atmospheric conditions. Its stability complies with the specifications usually prescribed for high-rise structures. In the calculations of the static and dynamic loads arising from the action of the wind, gusts with a wind speed of up to approximately 60 m/s were taken into account.

DISCUSSION

- Q. When will the GROWIAN be in operation?
- A. We expect to have it in operation in, roughly, two-and-a-half years.
- Q. Could you explain the emergency pitching apparatus in the event the electrical pitch control were to fail?
- A. As shown on that slide, there is a quick release bolt arrangement in the linkage connecting the pitch control actuator to the blade. In case of an emergency, it is activated and the blade becomes free. The blade then pitches itself to the feathered position by aerodynamic forces. The machine uses full span pitch control, as was specified by the government.
- Q. What is the weight of the machine and the blades?
- A. The weight of the machine is about 240 tons. The weight of the reinforced concrete is 750 tons, and each blade weighs 23 tons.

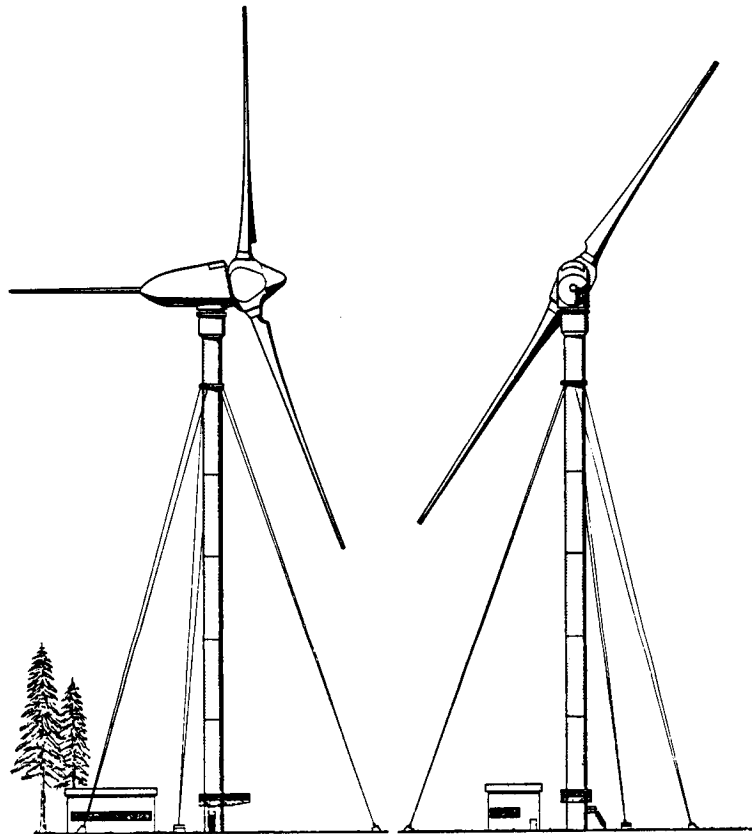


Figure 1. - Large wind energy converter GROWIAN 3 MW

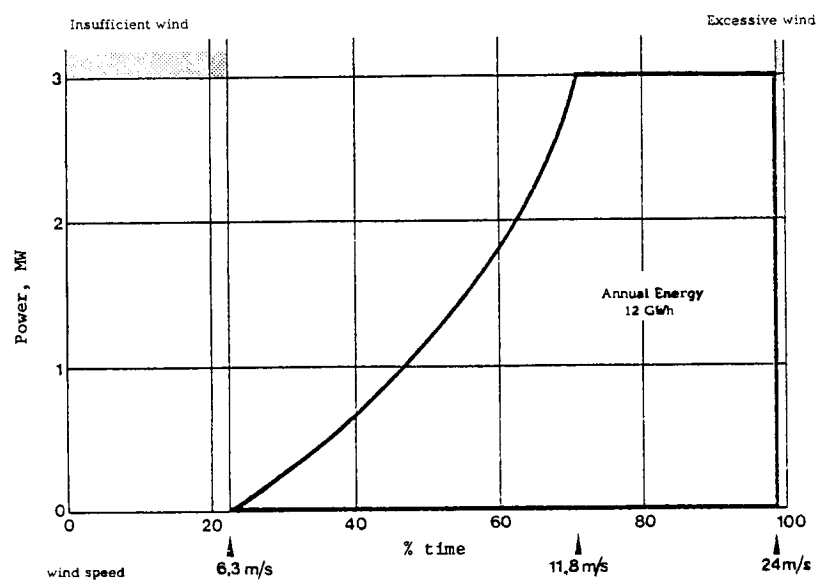


Figure 2. - Power duration curve.

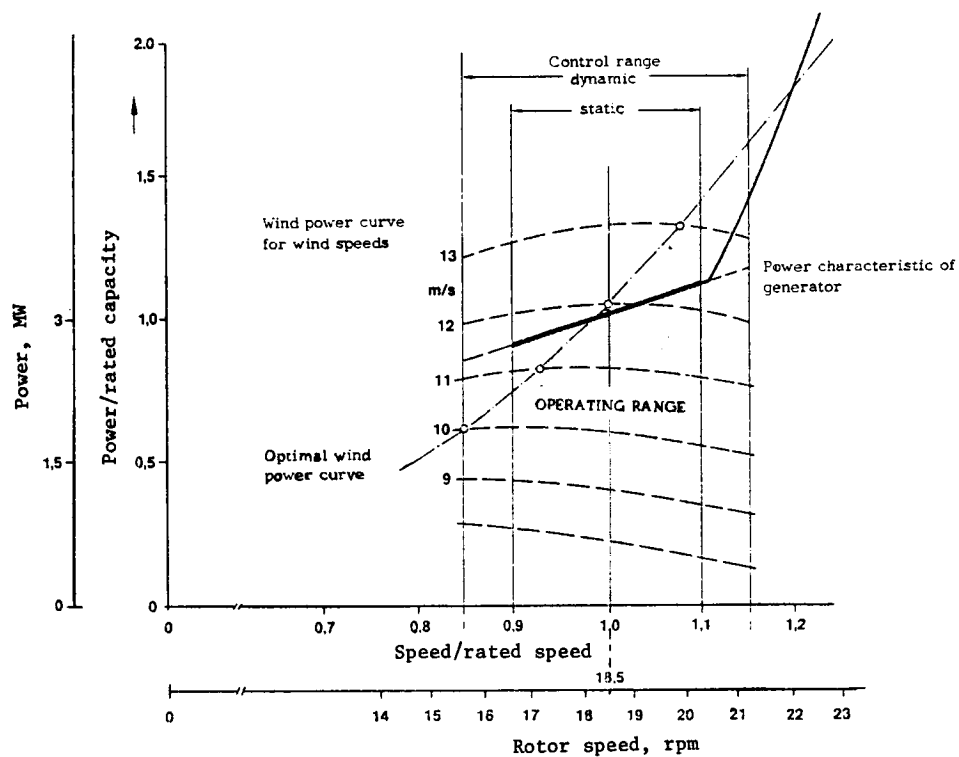


Figure 3. - Performance characteristics.

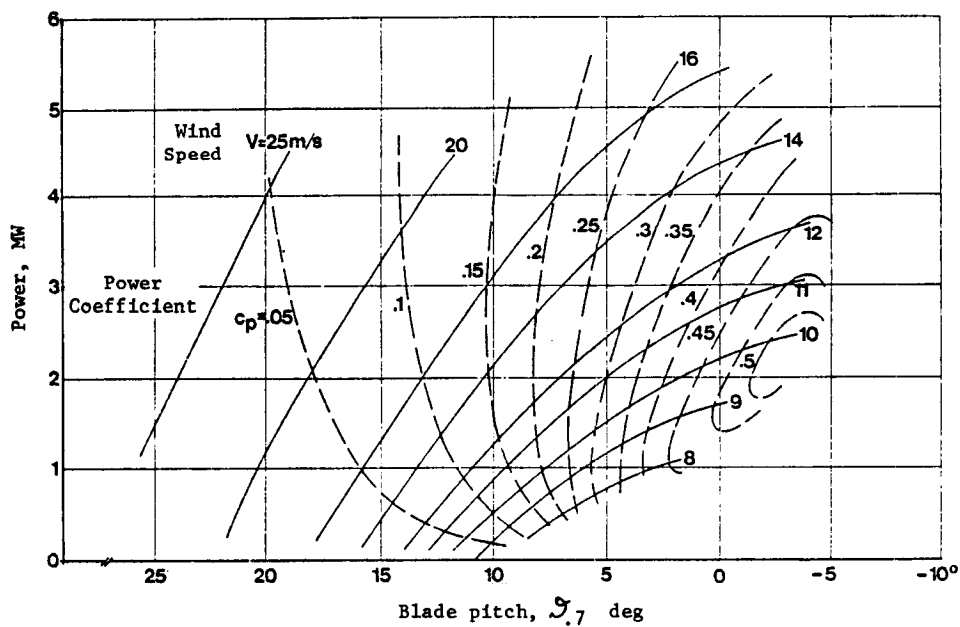


Figure 4. - Rotor performance.

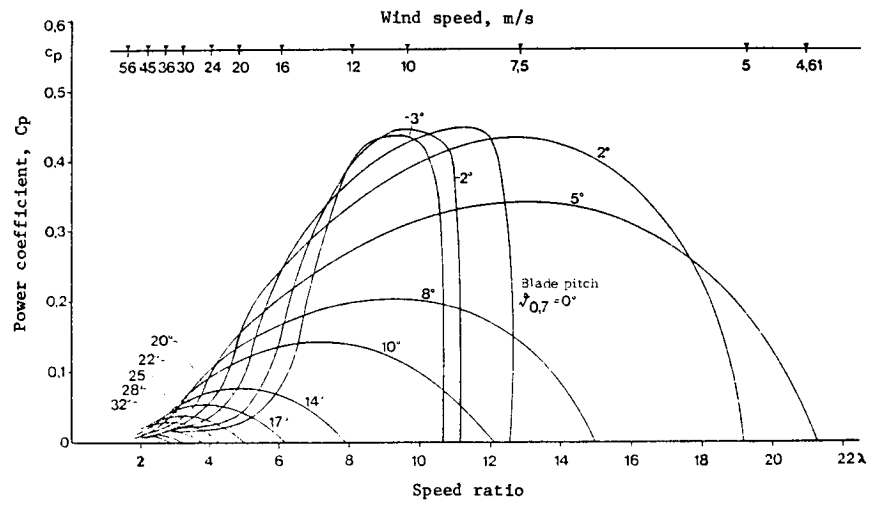


Figure 5. - Power coefficient chart.

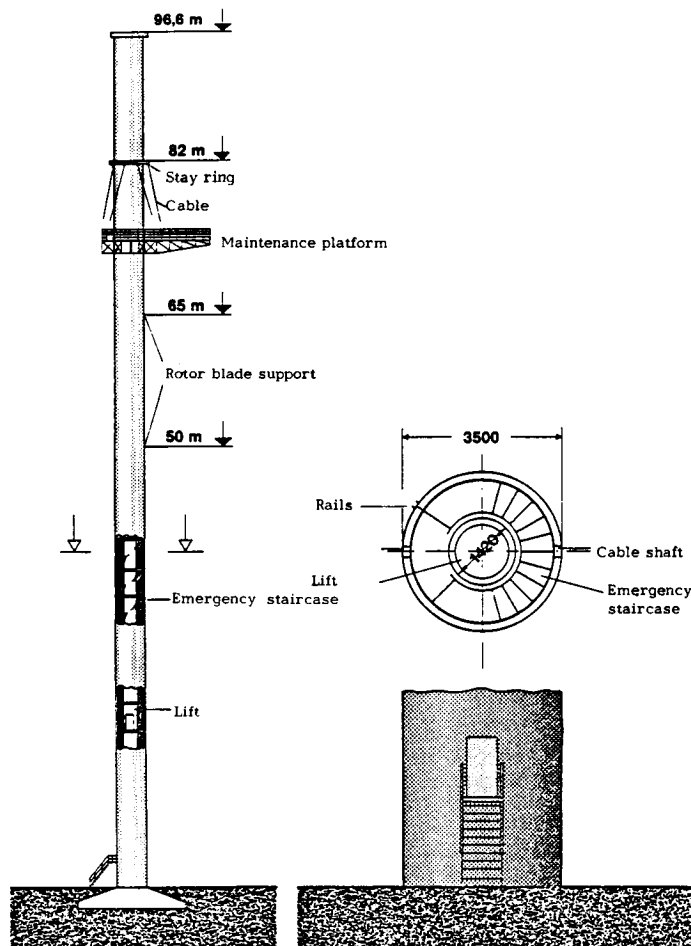


Figure 6. - Tower.

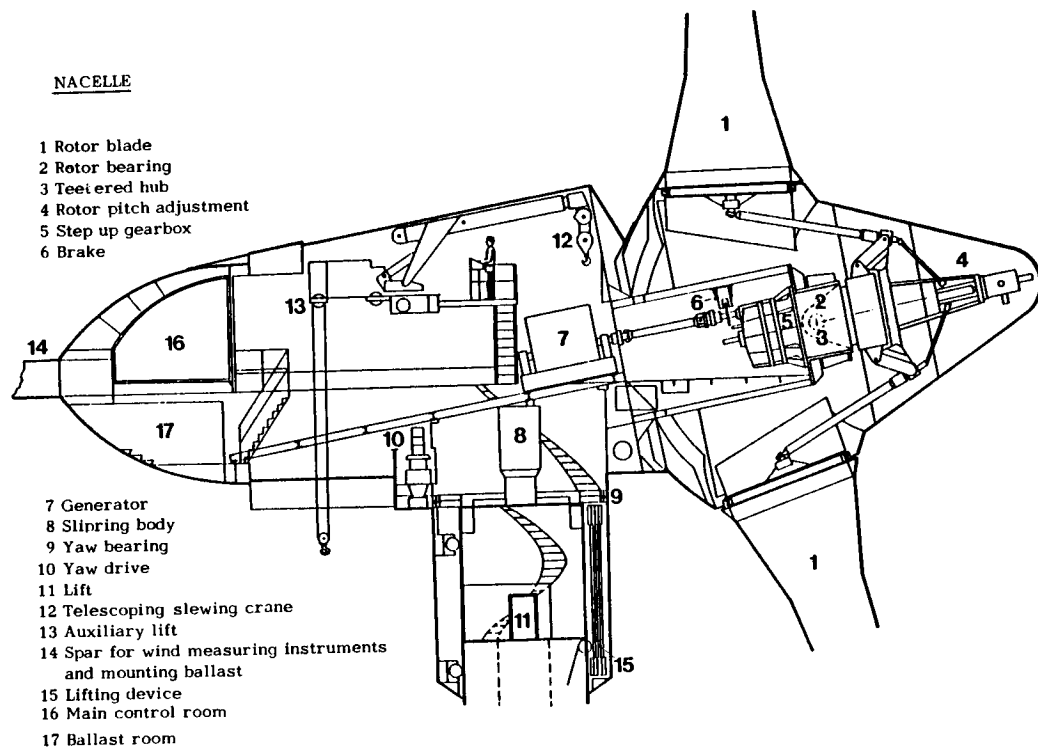


Figure 7. - Machine housing.

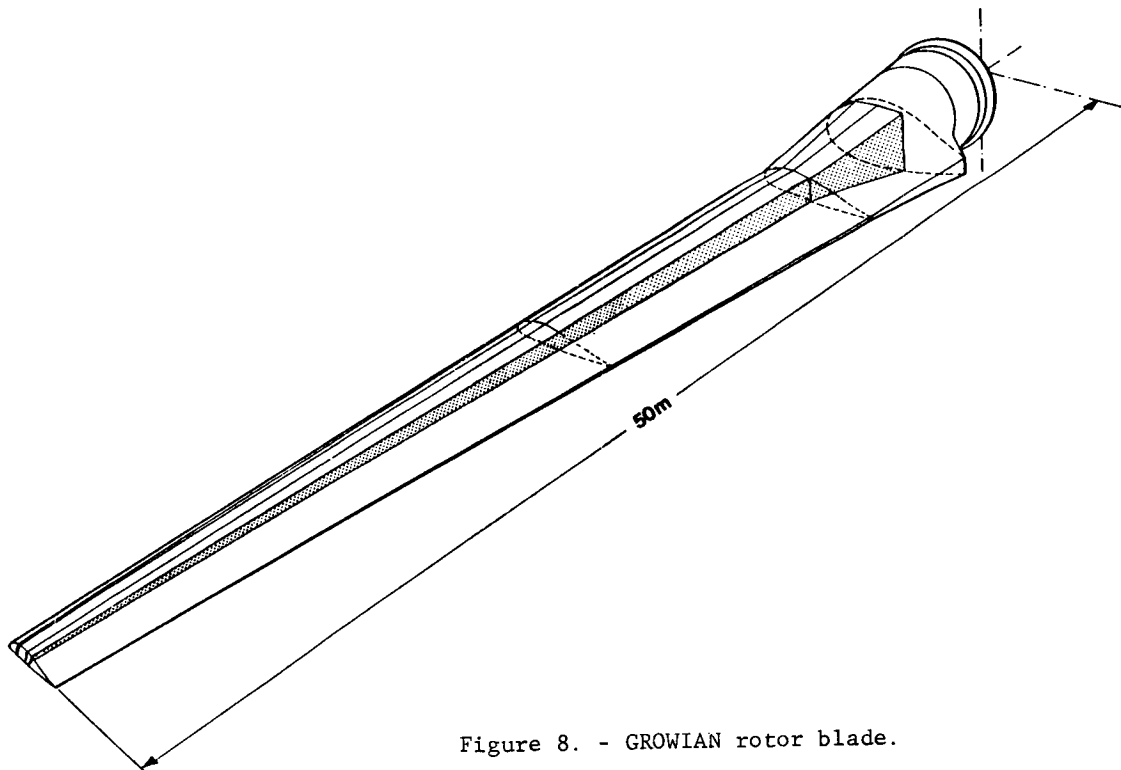


Figure 8. - GROWIAN rotor blade.

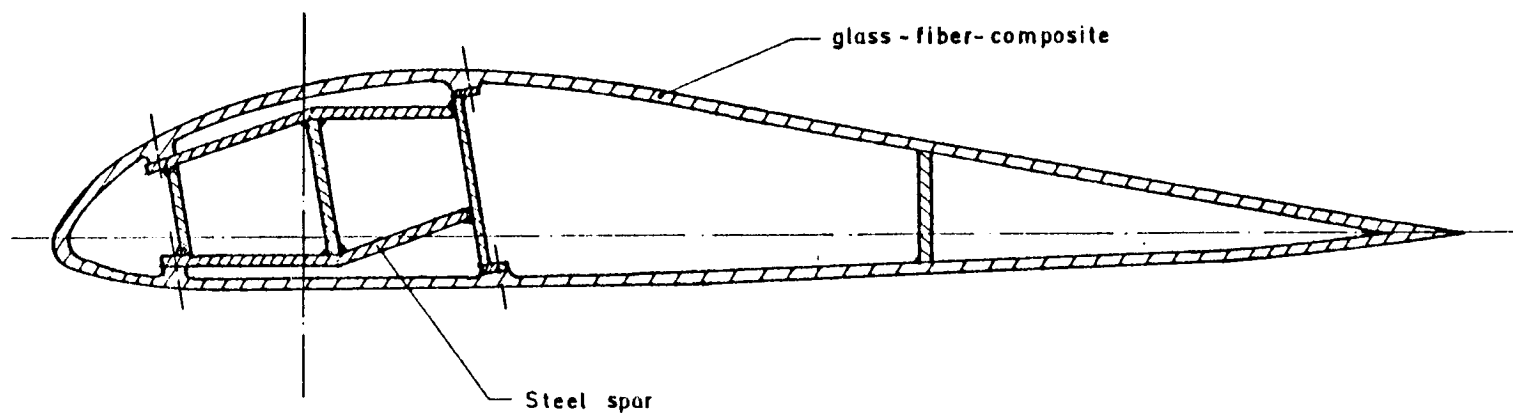
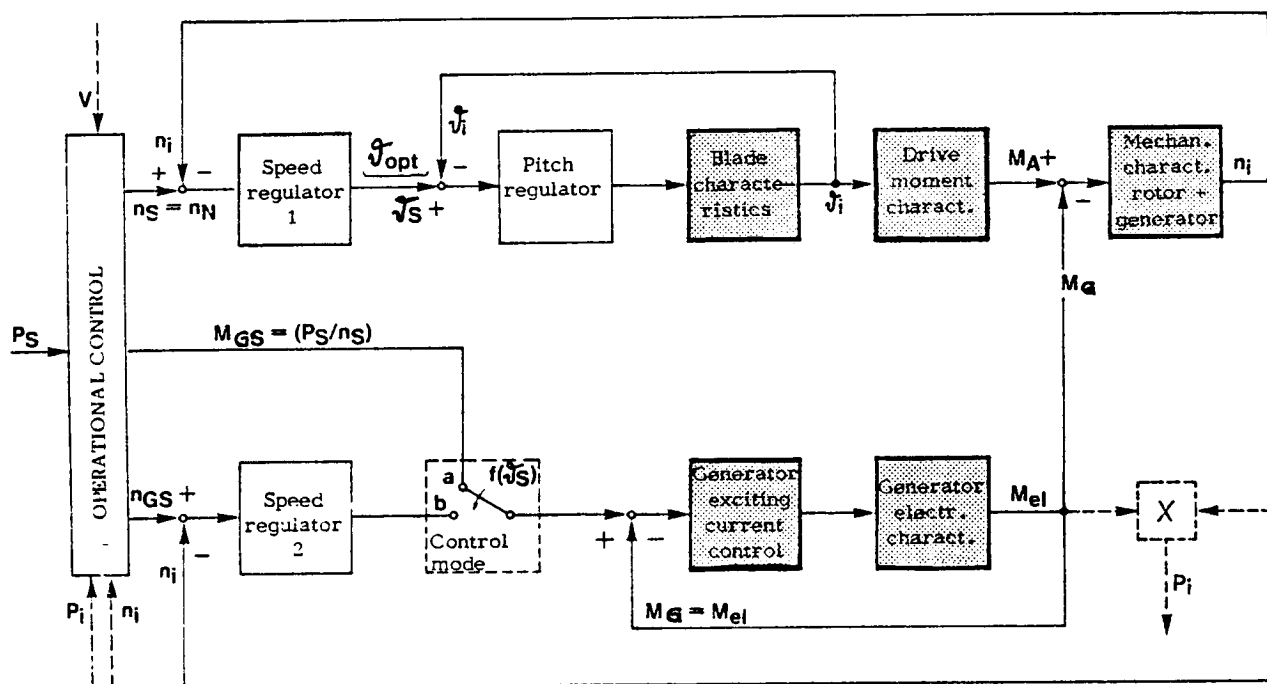


Figure 9. - Cross section of the rotor blade.



M = moment
n = speed of rotation
p = power
V = wind speed
 $\dot{\gamma}$ = rotor blade pitch

Indices:
A = drive
el = electric
G = generator

i = actual value
N = rated value
opt = optimum
S = nominal value

Figure 10. - Effective output-rotational speed control.

- 1 Crane
- 2 Cable equipment
- 3 Stay ring
- 4 Nacelle
- 5 Scaffolding
- 6 Mobile platform
- 7 Spar
- 8 Rotor
- 9 Mounting ballast
- 10 Hoist
- 11 Stay
- 12 Foundation for stay
- 13 Winch

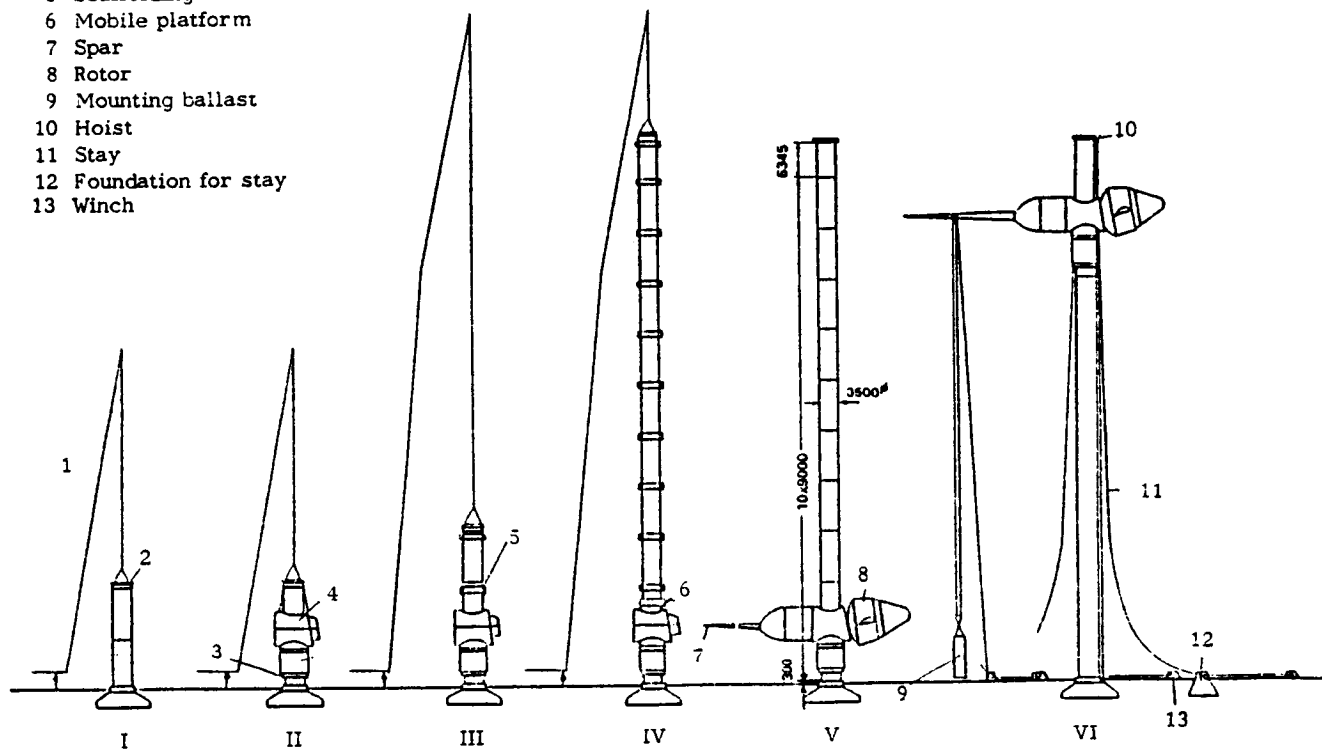


Figure 11. - Tower and machine housing assembly.